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SUMMARY

A recent modification of the methodology of profile analysis allows the testing for differences between two functions as a whole with a single test rather than point by point with multiple tests. This modified profile analysis is applied to the examination of the issue of motion/no-motion conditions on airplane simulators. The test problem was studied using the lateral deviation curve as a function of engine-cut speed of a piloted 737-100 simulator. The results of this application are presented along with those of more conventional statistical test procedures on the same simulator data. The modified profile analysis led directly to the conclusion that motion affects significantly the performance of the lateral-control task; the more conventional procedures arrived at the same conclusion. While the application of this new statistical procedure is a major concern of the subject report, the motion/no-motion finding is in itself an important result. The pilots subjectively attributed the superior performance under motion conditions to the ability to determine immediately the direction of the yaw induced by the engine cut. Under fixed-base conditions, a delay was incurred between detection of the engine cut (from the engine sound simulation) and the visual detection of the ensuing yaw.

INTRODUCTION

The express purpose of many flight-simulation experiments is to detect statistically measurable differences in the performance of the man/vehicle system under investigation as factors in the experiment are varied. Often the performance index of interest may be expressed as a function. Examples are voluminous, such as RMS path errors as functions of range (refs. 1 to 3), tracking errors as functions of time delay (refs. 4 to 6), pilot describing functions (refs. 7 to 9), and touchdown sink rates as functions of trial number (i.e., learning curves, refs. 10 to 12).

Most instances of statistical treatment of such data are in terms of multiple tests at succeeding values of the independent variables (refs. 1 to 12). The methodology of profile analysis (ref. 13) was recently modified by Myers (ref. 14) and has accommodated the testing of differences between functions as a whole with a single test rather than point by point with multiple tests. This new procedure provides a significant tool to the simulation researcher. Bothersome issues, such as how many points must be significantly different to declare the functions different, are eliminated.

Myers develops the statistical procedure in detail and addresses the power of the test and its implications on experimental design in reference 14. This paper presents the results of the application of this test procedure to an actual flight-simulation experiment.

The area of aircraft directional control on runways is potentially large in terms of simulator usage (ref. 15). As in any simulation application, the trade-off between simulator fidelity and complexity (cost) has arisen, particularly in the area of motion/no-motion requirements. In this vein, an examination of the effect of the speed at which an engine is cut on the lateral deviation of a 737-100 simulator during take-off roll (an aircraft ground certification test to determine minimum control speed ground) under motion/no-motion conditions provides a suitable application for evaluating the modified profile analysis techniques.

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SIMULATOR CHARACTERISTICS AND TEST CONDITIONS

Aircraft Mathematical-Model Characteristics

The mathematical model of a Boeing 737-100 aircraft included a nonlinear data package for all flight regions; a nonlinear engine model; and nonlinear models of servos, actuators, and spoiler mixers. The simulation of the basic airframe was well validated prior to its use in numerous studies.

For the subject study, the simulated aircraft was in the take-off configuration with the flight characteristics indicated in table I. Landing-gear dynamics included drag and cornering forces for each main gear and the nose gear, while the braking force was a single input (nondifferential). Runway roughness as a function of speed was simulated, although other runway characteristics (e.g., runway crown, runway joints, surface conditions, and weather) were not. Nose-wheel steering was disconnected and the pilot exercised only rudder control.

Computer Implementation

The mathematical model of the aircraft and the simulation hardware drives were implemented on the Langley real-time simulation system. This system, consisting of a Control Data CYBER 175 computer and associated interface equipment, solved the programmed equations 32 times a second. The average time delay from input to output (1.5 times the sample period) was approximately 47 msec.

Simulator Cockpit

The general-purpose cockpit of the Langley visual motion simulator (VMS) was configured as a transport cockpit. The primary instrumentation consisted of an attitude indicator (including active flight director bars and speed bug), vertical-speed indicator, a horizontal-situation indicator, altimeter, airspeed indicators (both calibrated and true), angles-of-attack and sideslip meters, and a turn and bank indicator. A stereo sound system was used to simulate engine noise.

The control forces on wheel, rudder pedals, and column are provided by a hydraulic system coupled with an analog computer. The system allows for the usual variable feel characteristics of stiffness, damping, backlash, coulomb friction, breakout forces, detents, and inertia. The force gradients can also be provided by the digital computer used to solve the aircraft mathematical model. Selection of the parameters of control loading system was included in the extensive validation process for the 737-100 flight simulator.

Visual Display

The Langley VMS is provided with an "out-the-window" virtual-image system of the beam-splitter, reflective-mirror type. The system, located nominally 1.27 m from the pilot's eye, presented a nominal 48° width by 36° height field of view of a 525 TV line raster system and provided a 46° by 26° instantaneous field of view. The system supplies a color picture of unity magnification with a resolution on the order of 9 minutes of arc.

The scene depicted in the virtual-image system was obtained from a terrain model board. The TV-camera transport system used in conjunction with a terrain model board is described in reference 16. The maximum in-plane speed capabilities of the system are 444 knots, with vertical speed capabilities of ±152 m/sec (±30 000 ft/min). The translational lags of the system are 15 msec or less and the rotational lags are 22 msec or less. The average total visual delay, including computational throughput delay, was thus less than 70 msec.

Motion System

The motion performance limits of the Langley visual motion simulator are shown in figure 1. These limits are for single-degree-of-freedom operation. Conservatism must be exercised in the use of the position limits since they change as the orientation of the synergistic base varies. References 17 to 19 document the characteristics of the system which possesses time lags of less than 50 msec. Thus, the average total motion delay, including computation throughput, is less than 100 msec (ignoring the lead introduced by washout) and is quite compatible with the visual delays. The washout system used to present the motion-cue commands to the motion base is nonstandard. It was conceived and developed at Langley Research Center and it is documented in references 20 to 22. A brief description and the specific parameters of the nonlinear coordinated adaptive washout used in this study are presented in the appendix.

Test Conditions

A simulation of a ground certification test for transport aircraft was selected for the application of the new statistical procedure. The certification test determines the effect of the speed at which an engine is cut on the lateral runway deviation of an aircraft during take-off roll. The nose-wheel steering was disconnected for this maneuver and the test runs were initiated with the simulated aircraft accelerating slowly down the runway from a trimmed

airspeed of 60 knots. Flaps were set at 15° and spoilers were stowed. The throttles were set to give 25 350 N from each engine. As the simulated aircraft accelerated through the target airspeed, one throttle was instantaneously closed to idle through computer program control. As soon as the pilot perceived the resulting lateral acceleration and/or yaw of his aircraft, he arrested the lateral deviation with an appropriate rudder input. The maximum lateral deviation measured from the initial deviation at throttle closure (deviation from the center line) was then recorded along with the target airspeed for a range of target airspeeds under both fixed- and motion-base conditions. Since rudder effectiveness decreases as airspeed decreases, the task difficulty, as measured by the lateral deviation, increases at lower speeds. The velocity at which a specified lateral deviation (e.g., 7.62 m) is exceeded is the minimum control speed ground which is used as an aircraft ground certification parameter.

MODIFIED PROFILE ANALYSIS

The methodology developed in reference 14 was used to test for statistical differences between the two lateral deviation functions of airspeed for motion/no-motion conditions. The methodology is described here as applicable to only two functions, although reference 14 treats the general case as well.

Methodology

The concept of a multivariate test for function differences arose from contemplation of the meaning of the motion-airspeed interaction term in a univariate analysis of variance. If both the motion main effect and the motion-airspeed interaction term were significant, it would imply that the effect of motion on the lateral deviation was different at different airspeeds. Thus, the two functions would be different. Extension of this concept to a single test led to development of modified profile analysis.

Let

$$\vec{y}_i = \left[y_{ij}\right] = \begin{bmatrix} y_{i1} \\ y_{i2} \\ \cdot \\ \cdot \\ \cdot \\ y_{is} \end{bmatrix} \qquad \left(i = \begin{cases} 1 & \text{motion} \\ 2 & \text{fixed base} \end{cases}\right) \qquad (j = 1, 2, \ldots, s)$$

where s is the number of airspeeds and y is the lateral deviation. Thus, $\vec{y}_1$ is a vector consisting of the function values (lateral deviation) at each airspeed, for the motion condition. It is assumed that this vector, and $\vec{y}_2$

as well, follows a multivariate normal distribution with common variance-covariance matrix Σ, which is an $s \times s$ matrix. The practical implication here is that within each function the observations are correlated and the correlation structure is the same for each of the two functions.

Replicate each function (or vector) r times in order to test the null hypothesis

$$H_0 : \vec{\mu}_1 = \vec{\mu}_2$$

where $\vec{\mu}_i$ is the vector of true means for the ith function.

Let $\hat{\Sigma}$ be the estimate of the variance-covariance matrix Σ obtained by pooling the sample variances and covariances for each function over both functions, and let $\vec{\bar{y}}_1$ be the vector of means.

Then

$$T^2 = \left(\vec{\bar{y}}_1 - \vec{\bar{y}}_2\right)' S^{-1}\left(\vec{\bar{y}}_1 - \vec{\bar{y}}_2\right)$$

where $S = \frac{2}{r}\hat{\Sigma}$, follows Hotelling's T^2-distribution (see ref. 13) with (2r - 2) degrees of freedom. The statistic $\frac{(2r - s - 1)}{(2r - 2)s} T^2$ follows an F-distribution with s and $(2r - s - 1)$ degrees of freedom. This fact allows testing of the hypothesis of equality of mean vectors using the upper tail of the F-distribution. If $\vec{\mu}_1 \neq \vec{\mu}_2$, the test statistic follows the noncentral F-distribution (ref. 13) with degrees of freedom $(s,\ 2r - s - 1)$ and with non-centrality parameter $\delta^2 = \frac{r}{2}\left(\vec{\mu}_1 - \vec{\mu}_2\right)'\Sigma^{-1}\left(\vec{\mu}_1 - \vec{\mu}_2\right)$. Thus, the estimated power of the test may be calculated for a specific difference $\left(\vec{\mu}_1 - \vec{\mu}_2\right)$ and for an estimate of Σ.

Experimental Design

Three experienced subjects (two pilots and one simulation engineer) made seven repetitions of each motion condition at each of seven airspeeds. The motion conditions were assigned in alternating pairs (i.e., runs 1 and 2 were fixed base, runs 3 and 4 were motion, etc.), while the airspeed and left or right engine-cut assignments were randomized. Left or right assignment of

engine cut only provided a detection task to the pilot, as the engine and rudder-power effects were symmetric.

OBJECTIVE RESULTS

Three types of analysis procedures were used on the collected data. Results from standard t-tests for mean differences between fixed- and motion-base performance (lateral deviations) at each airspeed and a detailed univariate analysis of variance (with related testing) provide an interesting comparison of the results obtained from the multivariate modified profile analysis.

Results of t-Tests

Table II presents the results of t-tests at each airspeed for differences in fixed- and motion-base means (averaged over pilots and replicates). The claim that motion affects pilot/simulator performance for the minimum-control-speed-ground task is clearly supported by this analysis. The means and standard deviations from table II are plotted in figure 2.

Analysis of Variance Results

A univariate analysis of variance was carried out on the data, using a $2 \times 3 \times 7$ full factorial design with seven replicates (motion condition, pilots, and airspeeds are treated as factors). Table III presents the results of this analysis of variance. The analysis reveals that motion is indeed a significant factor, as is airspeed. The motion-pilot and motion-airspeed interactions are also significant, and so is the third-order interaction. Therefore, the motion effect is different from pilot to pilot (AB) and at different airspeeds (AC). Also, the motion effect on pilots varies with airspeed (ABC). Because of this implied pilot dependence (even though the pilot factor is not significant), further analysis was carried out.

Table IV presents the results of t-test comparisons of motion- and fixed-base performance between the means of each pilot for each airspeed. These comparisons use the standard error of a difference s_d between treatment means,

$$s_d = \sqrt{\frac{2 \times (2.22)^2}{7}} = 1.19 \text{ m (246 degrees of freedom)}$$

based on a mean square error of 2.22 m from the analysis of variance, instead of the standard error of the previous t-test procedures (which would require a pooled standard deviation for each pilot at each airspeed, with 12 degrees of freedom). These t-test comparisons are equivalent to the more conventional contrast tests using F-values, but they have the advantage (in terms of clarity) of using means rather than sums of squares. As may be seen from the table,

pilots 1 and 3 (the simulation engineer) yield some significant motion-dependent results, especially at lower airspeeds. The results for pilot 2 are generally not significant.

Further analysis of the data reveals a significant learning curve for the motion-base performance of pilot 2. Table V compares the fixed- and motion-base performance, averaged over airspeed, of pilot 2 as a function of replicate number. The learning curve for the motion condition is quite evident. Table V also presents the t-test results, utilizing the standard error of a difference between treatment means (s_d = 1.19 m, 246 degrees of freedom), for the comparisons of these means. Once the learning curve "asymptotes," the effect of motion on pilot 2 is significant.

Modified-Profile-Analysis Results

The pilot factor was incorporated into the replicates for the purposes of this analysis, as was the case with the initial t-test data of figure 2 and table II. This procedure thus provided the parameters $s = 7$ (airspeeds) and $r = 21$ (replicates) for each function (lateral deviation as a function of airspeed for each motion condition). The Hotelling's F-test statistic, for 7 and 34 degrees of freedom, was calculated to be 13.303. This is found to be highly significant, since the 1-percent significance level F-value is 3.218. Thus, the null hypothesis that the two functions are the same (i.e., motion has no effect) is rejected without further analysis requirements.

SUBJECTIVE RESULTS

The pilots subjectively attributed the superior performance with motion to the ability to determine immediately which rudder was required. Under fixed-base conditions, the engine sound alerted the pilots to the engine cut, and a delay was incurred from this point until visual detection of the direction of the ensuing yaw was possible.

CONCLUDING REMARKS

The modification of the methodology of profile analysis to accommodate the testing of differences between two functions with a single test, rather than multiple tests at succeeding values of the independent variable, has been described and demonstrated. Other analyses of the simulator experimental data (an examination of the effect of motion/no-motion conditions on the lateral-deviation curve as a function of engine-cut speed of a 737-100 simulator) included the simple t-test procedure and the more sophisticated, detailed univariate analysis of variance.

The t-test procedure yielded solid evidence at each airspeed of motion effects. The analysis of variance procedure also led to the conclusion that motion affects simulator performance after a detailed analysis of pilot-dependent results. The modified profile analysis led directly to the con-

clusion that motion affects significantly the effect of the speed at which an engine is cut on the lateral deviation of a piloted flight simulator.

While all three procedures led to the same conclusion (a gratifying result), potential applications in which modified profile analysis may be used to solve conflicting multiple tests (significant and nonsignificant t-tests at different airspeeds, for example) are likely in examinations of effects that are not as clearly separated as the motion/no-motion conditions of this ground-handling task.

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DESCRIPTION OF WASHOUT SYSTEM AND PARAMETERS

The washout system used to present the motion-cue commands to the motion base is nonstandard. It was conceived and developed at Langley Research Center and it is documented in references 20 to 22. The basis of the washout is the continuous adaptive change of parameters to (1) minimize a cost functional through continuous steepest descent methods and (2) produce the motion cues in translational accelerations and rotational rates within the motion envelope of the synergistic base. The specific parameters of the nonlinear coordinated adaptive washout used in this ground-handling study are presented in the following table:

Symbol	Parameter	Value	Units
R_x	Components of vector from aircraft center of gravity to motion-base centroid	12.192	m
R_y		0.2286	m
R_z		1.7399	m
x_1	Longitudinal breakpoint	2.4284	m/sec^2
$S_{x,o}$	Longitudinal scale factor	0.5	
y_1	Lateral breakpoint	1.2192	m/sec^2
$S_{y,o}$	Lateral scale factor	0.5	
z_1	Vertical breakpoint	4.5720	m/sec^2
$S_{z,o}$	Vertical scale factor	0.5	
p_1	Roll breakpoint	0.25	rad/sec
$S_{p,o}$	Roll scale factor	0.7	
q_1	Pitch breakpoint	0.5	rad/sec
$S_{q,o}$	Pitch scale factor	1.0	
r_1	Yaw breakpoint	0.15	rad/sec
$S_{r,o}$	Yaw scale factor	1.0	
W_x	Pitch rate weight	0.00929	m^2/rad^2-sec^2
b_x	Longitudinal position penalty	0.01	sec^{-4}

APPENDIX

Symbol	Parameter	Value	Units
c_x	Longitudinal velocity penalty	0.2	sec^{-2}
d_x	Longitudinal damping	1.2727	rad/sec
e_x	Longitudinal frequency	0.81	rad/sec^2
γ_x	Longitudinal coordination gain	0.082	rad-sec/m
$K_{\lambda,x}$	Longitudinal gains	3.22917	sec^3/m^2
$K_{\delta,x}$		0.010764	sec^3/m^2
$K_{i,\gamma,x}$	Longitudinal gains on initial parameters	0.1	sec^{-1}
$K_{i,\delta,x}$		0.5	sec^{-1}
$\lambda_{x,MIN}$	Limits on longitudinal variables	-0.1	
$\lambda_{x,MAX}$		1.0	
$\delta_{x,MIN}$		0.0	
$\delta_{x,MAX}$		1.0	
$\dot{\lambda}_{x,MIN}$		-0.1	
$\dot{\delta}_{x,MIN}$		-1000.	
$\lambda_x(o)$	Initial conditions	1.0	
$\delta_x(o)$		0.5	
W_y	Roll rate weight	0.00929	$m^2/rad^2\text{-}sec^2$
b_y	Lateral position penalty	0.01	sec^{-4}
c_y	Lateral velocity penalty	0.2	sec^{-2}
d_y	Lateral damping	0.707	rad/sec
e_y	Lateral frequency	0.25	rad/sec^2
λ_y	Lateral coordination gain	0.0656	rad-sec/m
$K_{\lambda,y}$	Lateral gains	3.2292	sec^3/m^2
$K_{\delta,y}$		0.269098	sec^3/m^2

APPENDIX

Symbol	Parameter	Value	Units
$K_{i,\lambda,y}$	Lateral gains on initial parameters	0.1	sec^{-1}
$K_{i,\delta,y}$		1.5	sec^{-1}
$\lambda_{y,MIN}$	Limits on lateral variables	-0.1	
$\lambda_{y,MAX}$		0.4	
$\delta_{y,MIN}$		0.0	
$\delta_{y,MAX}$		0.3	
$\dot{\lambda}_{y,MIN}$		-0.1	
$\dot{\delta}_{y,MIN}$		-0.04	
$\lambda_y(o)$	Initial conditions	0.4	
$\delta_y(o)$		0.3	
b_z	Vertical position penalty	0.1	sec^{-4}
c_z	Vertical velocity penalty	0.1	sec^{-2}
d_z	Vertical damping	1.2727	rad/sec
e_z	Vertical frequency	0.81	rad/sec^2
$K_{\eta,z}$	Vertical gain	0.516668	sec^3/m^2
$K_{i,\eta,z}$	Vertical gain on initial parameter	0.05	sec^{-1}
$\eta_{z,MIN}$	Limits on vertical variables	0.0	
$\eta_{z,MAX}$		0.5	
$\dot{\eta}_{z,MIN}$		-0.06	
$\eta_z(o)$	Initial condition	0.5	
b_ψ	Yaw position penalty	1.0	sec^{-4}
e_ψ	Yaw time constant	0.3	rad/sec^2
$K_{\eta,\psi}$	Yaw gain	100.	sec/rad^2
$K_{i,\eta,\psi}$	Yaw gain on initial parameter	0.1	sec^{-1}

APPENDIX

Symbol	Parameter	Value	Units
$\eta_{\psi,MIN}$	Limits on yaw variables	0.0	
$\eta_{\psi,MAX}$		1.0	
$\dot{\eta}_{\psi,MIN}$		-0.4	
$\eta_{\psi}(o)$	Initial condition	1.0	
$C_{x,A}$	Lead compensation parameters	0.0069	sec^2
$C_{y,A}$		0.0069	sec^2
$C_{z,A}$		0.0069	sec^2
$C_{x,v}$		0.15	sec
$C_{y,v}$		0.15	sec
$C_{z,v}$		0.133	sec
C_{ψ}		0.12	sec
C_{θ}		0.12	sec
C_{ϕ}		0.12	sec
g	Gravitational constant	9.806178	m/sec^2
h	Program step size	0.03125	sec

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TABLE I.- CHARACTERIZATION OF THE 737-100 TAKE-OFF CONFIGURATION

[Linearized about 100 knots]

Weight, N	400 341
Center of gravity, percent M.A.C.	0.31
Flap deflection, deg	15
Landing gear	Down
Damping ratio for -	
Short period	0.562
Long period	0.089
Dutch roll	0.039
Period, sec, for -	
Short period	6.30
Long period	44.3
Dutch roll	5.12
Single engine thrust, N	25 350
Spoilers	Stowed

TABLE II.- t-TEST RESULTS AT EACH AIRSPEED

Airspeed, knots	Lateral deviation				t-value
	Fixed base		Motion base		
	Mean, m	Standard deviation, m	Mean, m	Standard deviation, m	
70	26.30	5.19	16.18	4.39	**6.82
75	8.67	3.29	6.64	2.00	**2.42
80	6.67	1.86	3.90	1.76	**4.96
88	4.23	1.58	2.87	1.14	**3.20
96	3.20	1.24	2.27	.90	**2.78
104	3.29	1.28	2.12	.86	**3.48
116	2.59	1.06	1.81	.87	**2.61

Significance level	0.05	0.01
Tabulated t-values one-tailed (40 degrees of freedom)	1.68	2.42

*Indicates 5-percent significance level.
**Indicates 1-percent significance level.

TABLE III.- COMPUTED F-VALUES FOR THE ANALYSIS OF VARIANCE

Factors	Degrees of freedom	Sum of squares, m^2	Mean square, m^2	Computed F-value	Tabulated F-value for a significance level of -	
					0.05	0.01
Motion, A	1	531.25	531.25	**111.35	3.84	6.63
Pilots, B	2	16.98	8.49	1.78	3.00	4.61
Airspeed, C	6	11 190.48	1865.08	**390.92	2.10	2.80
Replicates	6	23.76	3.96	.83	2.10	2.80
AB	2	85.98	42.99	**9.01	3.00	4.61
AC	6	673.86	112.31	**23.54	2.10	2.80
BC	12	77.88	6.49	1.36	1.75	2.18
ABC	12	127.67	10.64	**2.23	1.75	2.18
Error	246	1 173.66	4.77			
Total	293	13 901.53				

*Indicates 5-percent significance level.
**Indicates 1-percent significance level.

TABLE IV.- MOTION-PILOT-AIRSPEED COMPARISONS

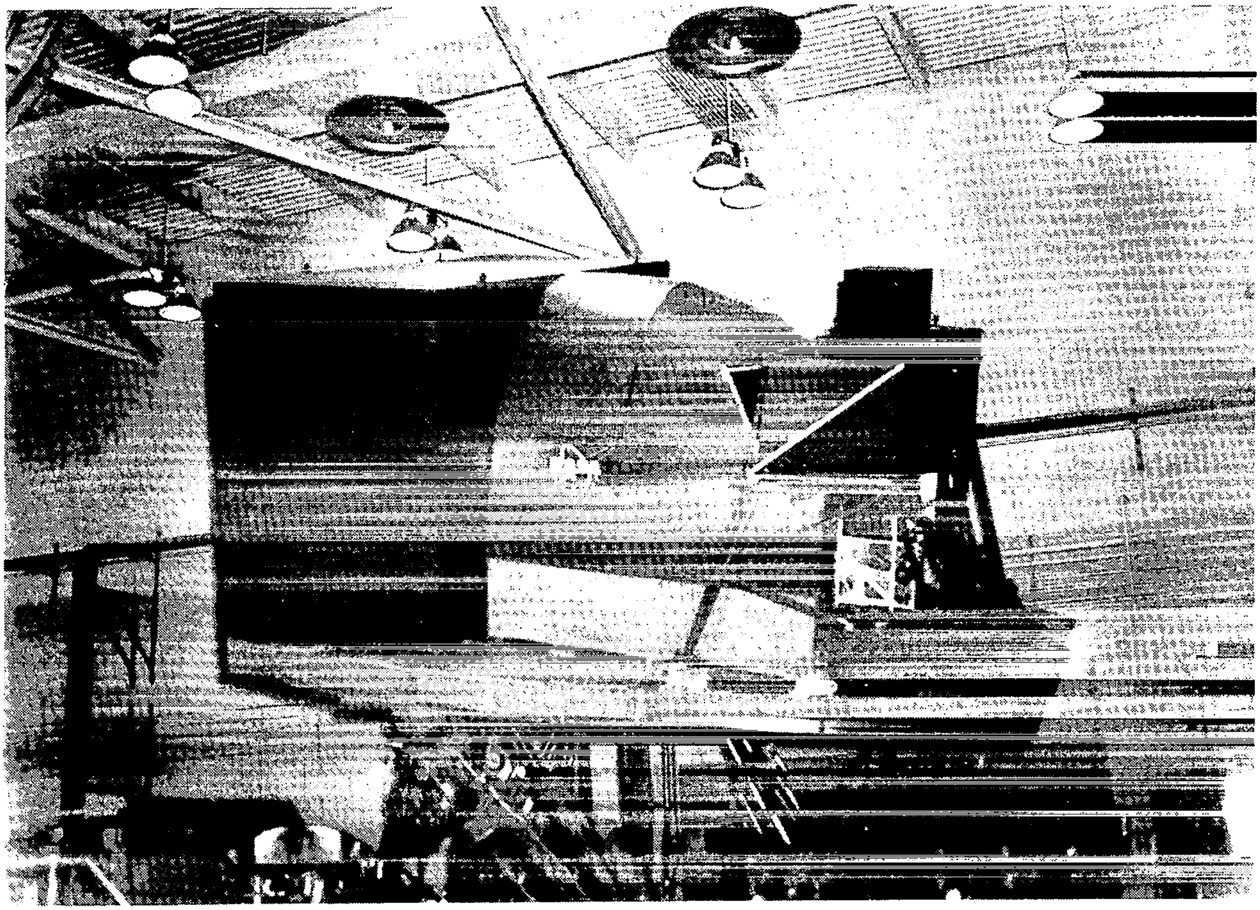
Airspeed, knots	Pilot	Lateral deviation				t-test, one-tailed
		Fixed base		Motion base		
		Mean, m	Standard deviation, m	Mean, m	Standard deviation, m	
70	1	27.94	5.36	13.94	2.10	**11.78
	2	25.02	5.50	20.42	4.74	**3.88
	3	25.94	5.06	14.19	2.42	**9.89
75	1	7.80	1.84	5.77	1.90	*1.71
	2	7.92	2.40	7.70	2.19	.19
	3	10.30	4.72	6.46	1.63	**3.23
80	1	6.05	1.88	3.24	0.95	**2.37
	2	6.16	1.23	5.01	1.91	.96
	3	7.79	2.07	3.44	1.90	**3.66
88	1	3.90	1.16	2.64	1.34	1.06
	2	3.60	1.21	3.17	.79	.36
	3	5.05	1.69	2.80	1.34	*1.89
96	1	2.54	0.84	2.04	1.16	0.42
	2	3.92	1.49	2.69	.83	1.04
	3	3.13	1.05	2.09	.59	.88
104	1	3.85	1.52	2.54	0.82	1.11
	2	2.97	.68	2.46	.85	.43
	3	3.06	1.47	1.37	.26	1.42
116	1	2.94	1.02	2.02	1.10	0.77
	2	2.32	.68	2.03	.85	.24
	3	2.52	1.42	1.38	.51	.96

*Indicates 5-percent significance level.
**Indicates 1-percent significance level.

TABLE V.- MOTION-REPLICATE COMPARISONS FOR PILOT 2

Replicate	Lateral deviation				t-test, one-tailed
	Fixed base		Motion base		
	Mean, m	Standard deviation, m	Mean, m	Standard deviation, m	
1	7.91	7.52	7.93	10.03	-0.017
2	6.25	5.96	6.84	7.36	-.50
3	6.63	7.03	5.98	6.54	.55
4	8.80	12.41	6.41	6.22	*2.01
5	7.56	7.80	5.60	6.27	*1.65
6	7.49	7.78	5.34	4.76	*1.81
7	7.26	8.30	5.30	5.58	*1.65
Average over replicates	7.42	7.83	6.20	6.48	1.03

*Indicates 5-percent significance level.
**Indicates 1-percent significance level.



	Position	Velocity	Acceleration
Pitch	+30, -20°	±15 deg/sec	±50 deg/sec^2
Roll	±22°	±15 deg/sec	±50 deg/sec^2
Yaw	±32°	±15 deg/sec	±50 deg/sec^2
Vertical	+0.762, -0.991 m	±0.610 m/sec	±0.6g
Lateral	±1.219 m	±0.610 m/sec	±0.6g
Longitudinal	+1.245, -1.219 m	±0.610 m/sec	±0.6g

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Figure 1.- Motion performance limits of the visual motion simulator.

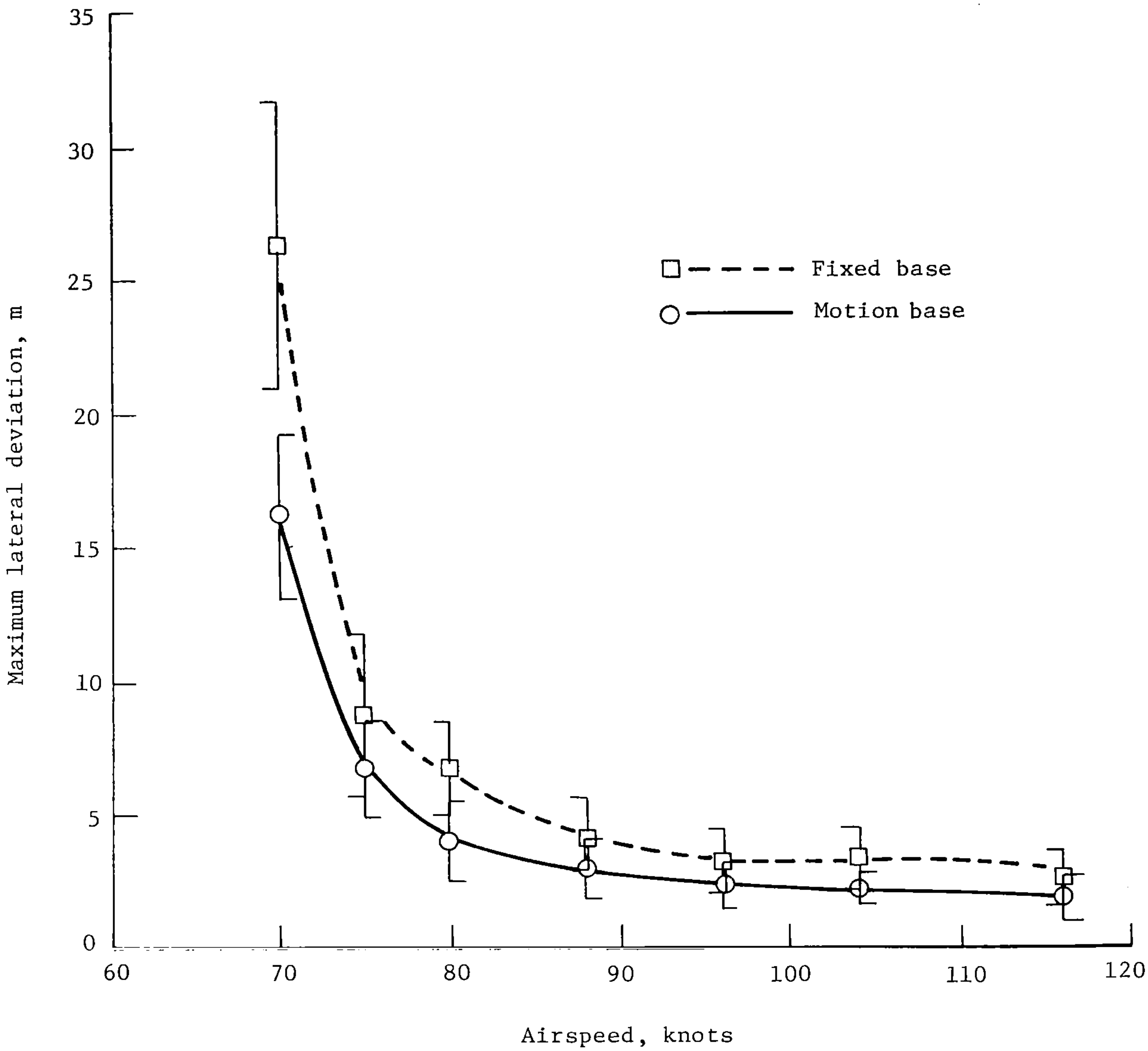

Figure 2.- Effect of engine-cut speed on the lateral deviation on the runway of a 737-100 simulator.

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16. Abstract

A recent modification of the methodology of profile analysis allows the testing for differences between two functions as a whole with a single test, rather than point by point with multiple tests. The modification is applied to the examination of the issue of motion/no-motion conditions as shown by the lateral-deviation curve as a function of engine-cut speed of a piloted 737-100 simulator. The results of this application are presented along with those of more conventional statistical test procedures on the same simulator data. The modified profile analysis led directly to the conclusion that motion affects significantly the performance of the lateral-control task; the more conventional procedures arrived at the same conclusion. While the application of this new statistical procedure is a major concern of the subject report, the motion/no-motion finding is in itself an important result.

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